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Hydro magnetic squeeze film in a rough porous parallel surface bearing of infinite width: A comparative study

Ankit S. Acharya[1], R.M. Patel[2] & G.M.Deheri[3]

[1]Department of Applied Sciences and Humanity, L.J Engineering College, Ahmedabad. Email: ankitacharya1984@gmail.com

[2]Department of Mathematics, Gujarat Arts and Science College, Ahmedabad- 380006, Gujarat State, India. Email: rmpatel12711@gmail.com

[3]Department of Mathematics, Sardar Patel University, Vallabh vidyanagar-388120, Gujarat State, India. Email:gm.deheri@rediffmail.com

Abstract

This investigation aims to study the Ferro fluid lubricated squeeze film performance in rough, porous parallel surface bearing of infinite width. The magnetic fluid flow model of Neuringer and Rosenweig has been used. Two different forms of the magnitude of magnetic field have been considered. The stochastic model of Christen and Tonder has been deployed to evaluate the effect of surface roughness. After solving the concerned stochastically averaged Reynolds' type equation the pressure distribution in the bearing system is obtained. Then the load carrying capacity is calculated for both the forms of the magnitude of the magnetic field. The results suggest that the magnetization offers a limited help in reducing the adverse effect of roughness and porosity. However, the situation remains better when the trigonometric form of the magnitude is employed.

Keywords: Squeeze film, Ferro fluid lubrication, Rough surface, Bearing of infinite width, Load bearing capacity.

AMS Subject Classification (2010): 97M10, 76W99

Introduction

Hsu et. al. (2003) discussed the combined effects of couple stresses and surface roughness on the lubrication of short journal bearings. Compared to the Newtonian lubricant smooth bearing case the couple stress effects and the longitude roughness improve the load carrying capacity. Gururajan and Prakash (2008) studied the surface roughness effects in infinitely long porous journal bearings. There was considerable influence of surface roughness. Tanner (2011) considered an isothermal short journal bearing with non-Newtonian lubricants. An approximate method for predicting the temperature distribution was compared with the experimental result. Patel et. al. (2010) dealt with the lubrication of an infinitely long bearing by a magnetic fluid. The friction was found to be decreasing at the moving plate while it increased marginally due to the magnetization. Patel et. al. (2011) conducted a study on the performance of a ferro fluid based short journal bearing. It was found that load carrying capacity increased nominally while the coefficient of friction decreased significantly.

Hsu et. al. (2013) considered the lubrication performance of short journal bearing considering the effect of surface roughness and magnetic field. The combined influence reduced the modified friction coefficient. Patel and Deheri (2013) analysed the effect of slip velocity on the performance of a short bearing lubricated with a ferrofluid. For any type of improvement the slip was required to be kept at minimum level. Shukla and Deheri (2016) studied the effects of slip velocity on the performance of a magnetic fluid based transversely rough porous narrow journal bearings. The combined effect of slip and transverse roughness decreased the load carrying capacity heavily. Shimpi and Deheri (2013) discussed the effect of deformation on a ferrofluid based transversely rough short bearing. Here the friction remains unchanged because of magnetic fluid lubrication but the load carrying capacity increased for almost all the value of deformation. Agrawal et. al. (2013) analysed the hydro dynamic lubrication in infinitely long journal bearing with oscillating velocity.

Different forms of the magnitude of the magnetic field have been studied. But no comparison is available in the literature. Therefore, here an attempt has been made to compare the performance taking different forms of the magnitude, for a squeeze film in a rough porous parallel surface bearing of infinite width.

Analysis:

The parallel surface squeeze film bearing and the associated coordinate system is presented below in figure (I).

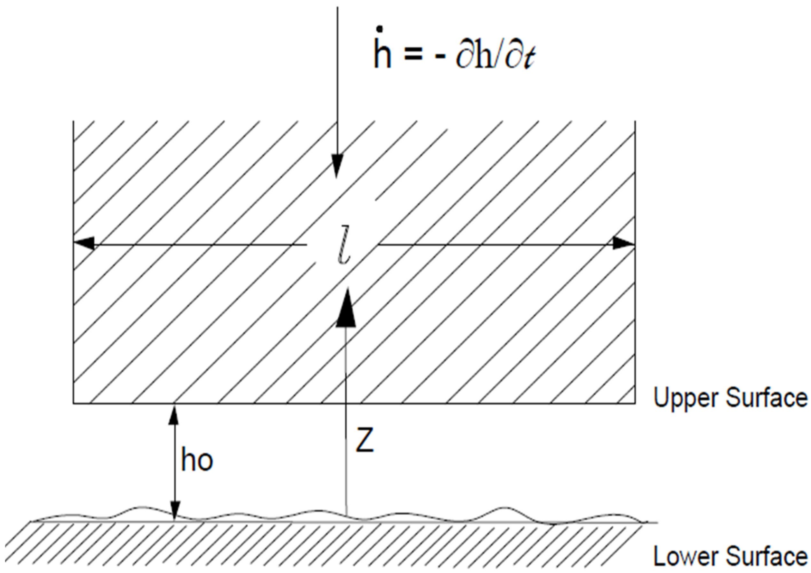

Figure: - I Geometry and configuration of the bearing system

Following the discussions of Patel et al. (2010, 2015), Bhat (2003) the magnetic fluid lubrication results in the Reynolds' equation.

$$\frac{\partial^2}{\partial x^2}\left(p - 0.5\mu_0\bar{\mu}H^2\right) = -\frac{12\mu\dot{h}}{h^3} \qquad \ldots(1)$$

where μ_0 is the permeability of the free space, $\bar{\mu}$ is the magnetic susceptibility, μ is the fluid viscosity. The bearing surfaces are assumed to be transversely rough. The geometry of the local film thickness can be thought of as consisting of two parts:

$$h(x) = \bar{h}(x) + h_s(x)$$

where $\bar{h}(x)$ is the mean film thickness and $h_s(x)$ is the deviation from the mean film thickness characterizing the random roughness of the bearing surfaces. $h_s(x)$ is considered to the stochastic in nature and governed by the probability density function $f(h_s)$, $-c \le h_s \le c$ where c is the maximum deviation from the mean film thickness. The mean α, the standard deviation σ and the parameter ε which is the measure of symmetry of random variable h_s, are defined by relationships.

$$\alpha = E(h_s),$$
$$\sigma^2 = E\left[(h_s - \alpha)^2\right]$$

and

$$\varepsilon = E\left[(h_s - \alpha)^3\right]$$

where the expectancy operator E is defined by

$$E(R) = \int_{-c}^{c} Rf(h_s)\,dh_s$$

While

$$f(h_s) = \begin{cases} \dfrac{35}{32c^7}\left(c^2 - h_s^2\right)^3, & \text{if } -c \le h_s \le c \\ 0, & \text{elsewhere} \end{cases}$$

In view of the stochastic averaging method of Christen and Tonder (1969.a, 1969.b, 1970), Prajapati (1995) the above equations transforms to

$$\frac{\partial^2}{\partial x^2}\left(p - 0.5\mu_0\bar{\mu}H^2\right) = -\frac{12\mu\,\dot{h}}{g(h)} \qquad \ldots(2)$$

where

$$g(h) = h^3 + 4\sigma^2 h + 3h\alpha^2 + 2h^2\alpha + 4\sigma^2\alpha + \alpha^3 + \varepsilon + 12\,\phi\,H$$

For the comparison of the following two different forms have been picked up

Form I

$$H^2 = k\left(x^2 - \frac{l^2}{4}\right) \qquad \ldots(3)$$

Form II

$$H^2 = kl^2\left(\frac{3\pi x}{2l} + \frac{3\pi}{4}\right)\cos\left(\frac{3\pi x}{2l} - \frac{\pi}{4}\right) \qquad \ldots(4)$$

where k is a suitably chosen constant so as to manufacture a required magnetic strength.

The boundary conditions associated are

$$p = 0 \text{ when } x = \pm\frac{1}{2}$$

Solving the modified Reynolds' equation (2), one gets the pressure distribution in the form of

$$p_1 = \frac{3}{2}\frac{\mu \dot{h}}{g(h)}\left(l^2 - 4x^2\right) + 0.5\mu_0\,\bar{\mu}\,k\left(x^2 - \frac{l^2}{4}\right) \qquad \dots(5)$$

for the Form I and

$$p_2 = \frac{3\mu\dot{h}}{2g(h)}\left(l^2 - 4x^2\right) + 0.5\mu_0\bar{\mu}kl^2\left(\frac{3\pi x}{2} - \frac{\pi}{4}\right) \qquad \dots(6)$$

for the Form II.

It is easily seen from p_1 that pressure distribution is parabolic in nature for the Form I while this profile appears to be distorted in the Form II

Then the load carrying capacity is calculated as

$$w_1 = \int_{-\frac{1}{2}}^{\frac{1}{2}} p_1\, dx = \frac{\mu\dot{h}}{g(h)}l^3 - \frac{\mu_0\bar{\mu}\,k\,l^3}{12} \qquad \dots(7)$$

In case of Form I while

$$w_2 = \int_{-\frac{1}{2}}^{\frac{1}{2}} p_2\, dx = \frac{\mu\dot{h}}{g(h)}l^3 + 0.5\mu_0\bar{\mu}\,k\,l^3\left[1 + \frac{2}{3\pi}\right] \qquad \dots(8)$$

with regards to Form II.

Introducing the following dimensionless quantities

$$\bar{x} = \frac{x}{l} \qquad \mu^* = -\frac{k\mu_0\bar{\mu}h^3}{\mu\dot{h}} \qquad P = -\frac{ph^3}{\mu\dot{h}l^2}$$

$$W = \frac{wh^3}{\mu\dot{h}l^3} \qquad \varepsilon^* = \frac{\varepsilon}{h^3}, \qquad \sigma^* = \frac{\sigma}{h},$$

$$\alpha^* = \frac{\alpha}{h}, \qquad \psi = \frac{\phi H}{h^3},$$

$$G(h) = \frac{g(h)}{h^3} = 1 + 4\sigma^{*2} + 3\alpha^{*2} + 2\alpha^* + 4\sigma^{*2}\alpha^* + \alpha^{*3} + \varepsilon^* + 12\psi$$

The non-dimensional load carrying capacity is calculated as

$$W_1 = \frac{1}{G(h)} + \frac{\mu^*}{12}$$

$$= 0.83\mu^* + \frac{1}{G(h)} \qquad \dots(9)$$

while for form II

$$W_2 = \frac{1}{G(h)} + \mu^*\left[1+\frac{2}{3\pi}\right]$$

$$= 1.212\mu^* + \frac{1}{G(h)} \qquad \ldots(10)$$

Obviously from equations (9) and (10) it is seen that the load carrying capacity remains more in the case of form (II).

Results and discussion:

It is seen from equation (9) and (10) that the non-dimensional load carrying capacity enhances

by $$\frac{\mu^*}{12} \approx 0.083\mu^*$$

and $$\frac{\mu^*}{2}\left(1+\frac{2}{3\pi}\right) \approx 1.212\mu^*$$

as compared to the case of traditional lubricant based bearing system. This establishes that the increase in load carrying capacity remains more in the case of the trigonometric form of the magnitude of the magnetic field.

In the absence of magnetization this investigation turns to the discussion of Prakash and Vij (1973) for smooth bearing system. The results presented in graphical form confirm that the load carrying capacity increase sharply due to the magnetization, increase being more in the case of trigonometric form (Figures 11-14).This is because the viscosity gets increase due to magnetization, causing increased pressure and load carrying capacity.

It is seen from Figures (4 and 14) that the effect of porosity on the distribution of load carrying capacity with respect to μ^* remains nominal up to the porosity value 0.001 for both the forms of magnitude. Further the effect of porosity and standard deviation remains adverse. Here also the effect of porosity remains marginal up to the value $\psi = 0.001$. It is seen from Figures (8-9) that variance (+ve) decreases the load carrying capacity while reverse is true in the case of variance (-ve) in addition. The porosity effect remains negligible up to the value of $\psi = 0.001$Further, it is seen from Figures(8-10) effect of skewness is almost identical with that the variance so far as to load carrying capacity negatively skewed roughness results in the enhanced load. It is easily observed that for this types of bearing system the combined effect of negatively skewed roughness and a variance may play a crucial role for enhancing the squeeze film behaviour.

Variation of load carrying capacity with respect to σ^* given in figures suggest that the standard deviation causes severe load reduction. The graphically results presented here indicate that the effect of Ferro fluid lubrication enhances further in the case of negatively skewed roughness particularly when variance (-ve) occurs.

Conclusion:

The trigonometric form of the magnitude of magnetic field ensures a relatively better performance as compared to the algebraic form of the magnitude in spite of the fact that the effect of transverse roughness and porosity is adverse in general. This type of bearing systems support a good amount of load even in the absence of flow which never happens in the case of conventional lubricant based bearing system. Needless to say that this investigation offers an additional degree of freedom.

This investigation reveals that the roughness must be accorded porosity while designing the bearing designing the bearing system even if a suitable form of the magnitude of the magnetic field has been considered.

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Figure: 1 Variation of load carrying capacity with respect to $\mu^*$and σ^*

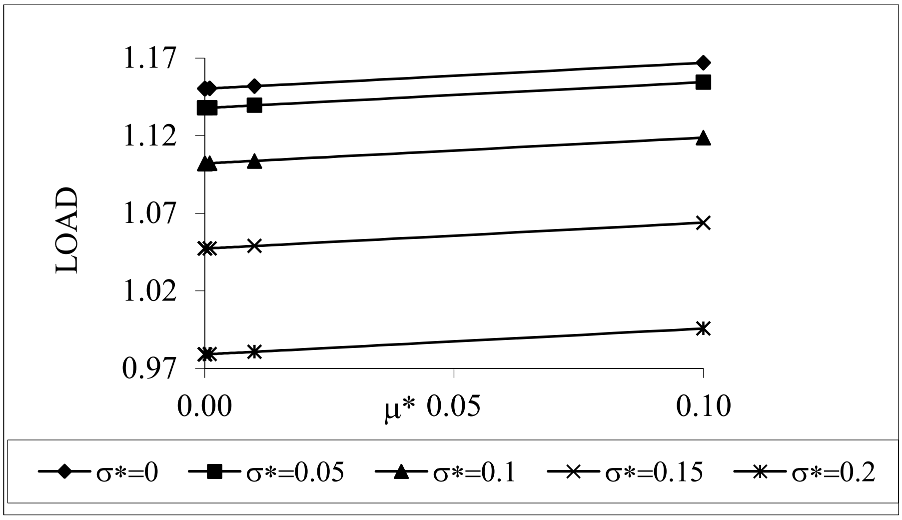

Figure: 2 Variation of load carrying capacity with respect to μ^* and α^*

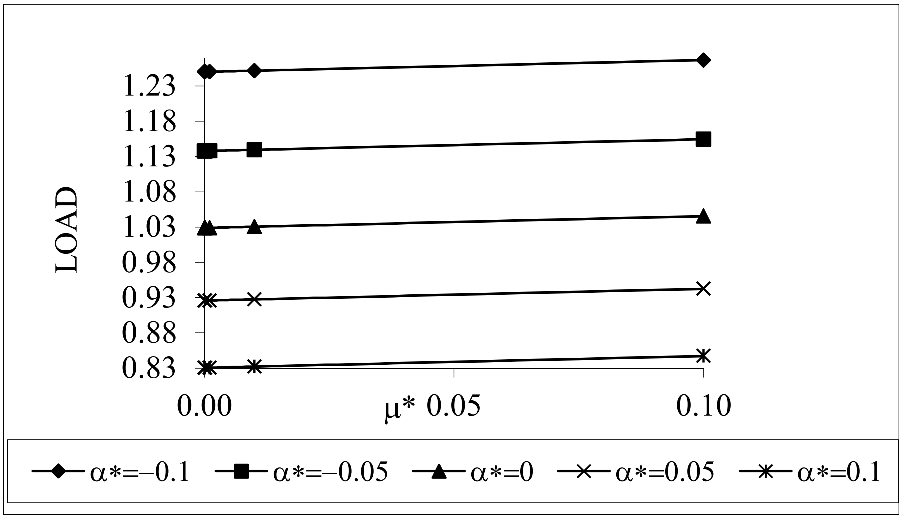

Figure: 3 Variation of load carrying capacity with respect to μ^* and ε^*

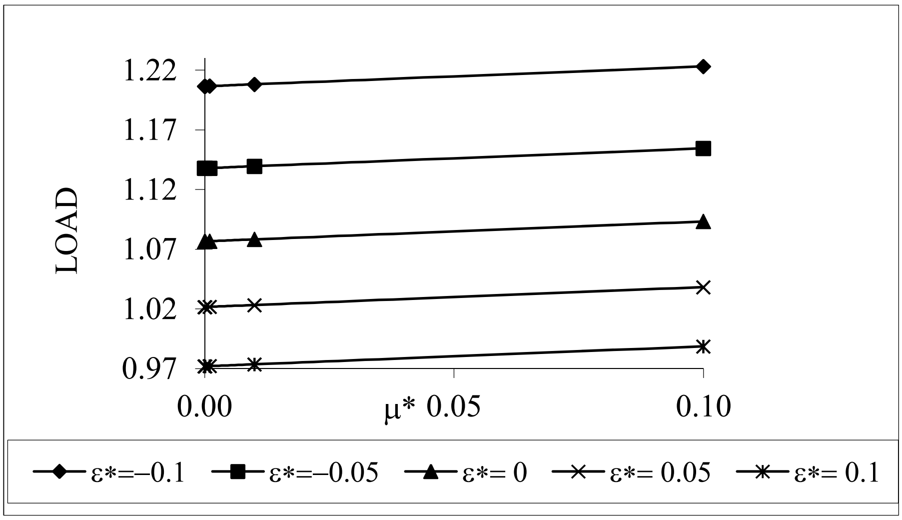

Figure: 4 Variation of load carrying capacity with respect to μ^* and ψ

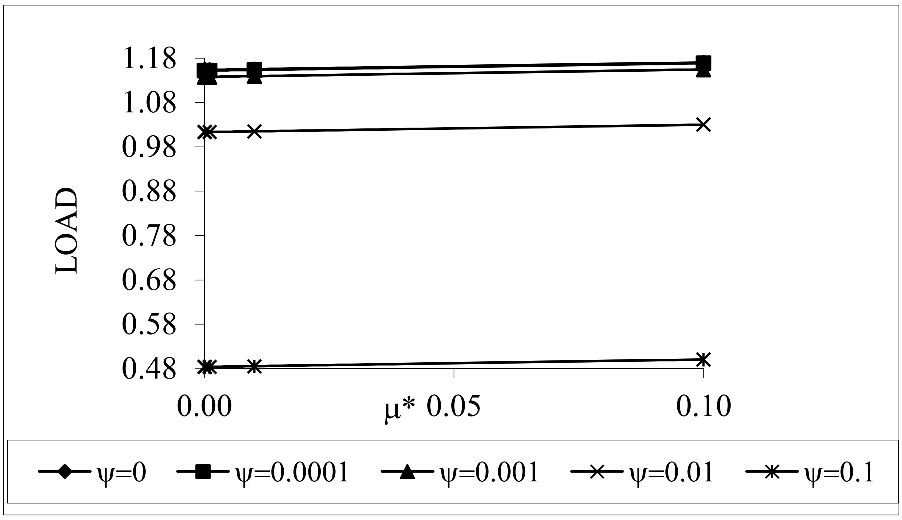

Figure: 5 Variation of load carrying capacity with respect to σ^* and α^*

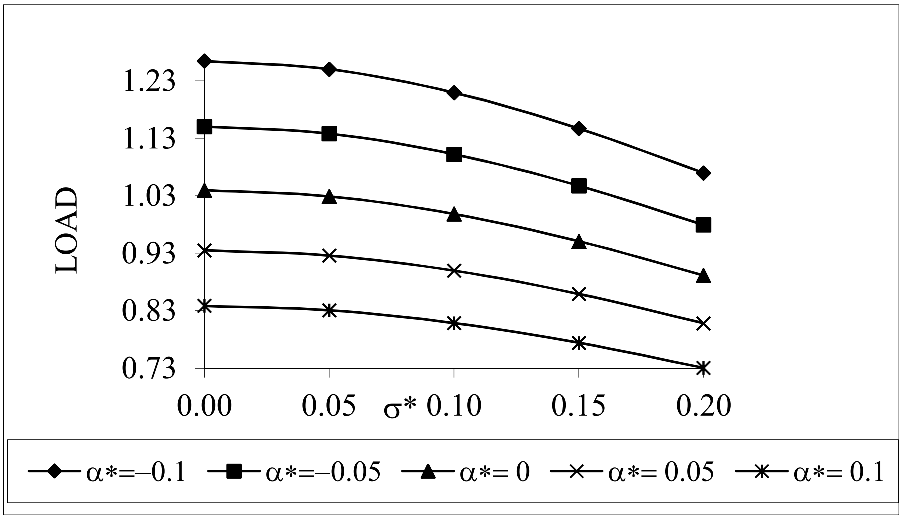

Figure: 6 Variation of load carrying capacity with respect to σ^* and ε^*

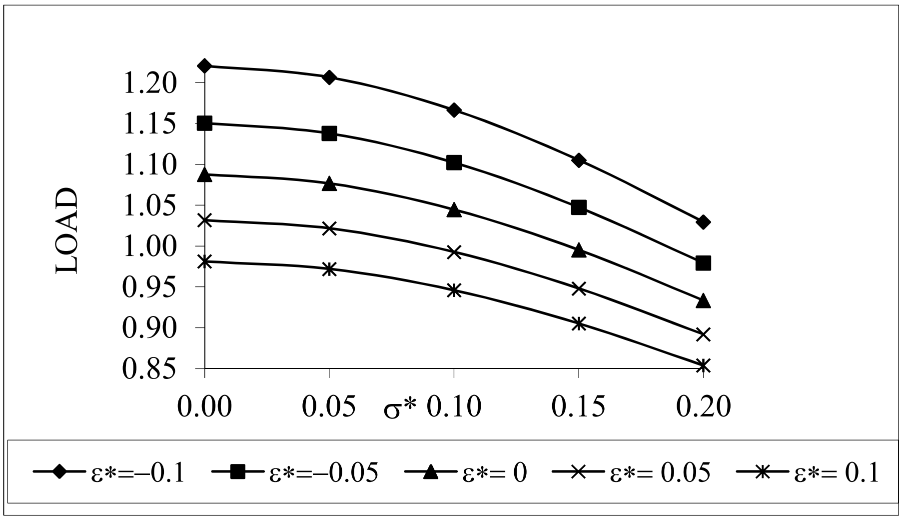

Figure: 7 Variation of load carrying capacity with respect to σ^* and ψ

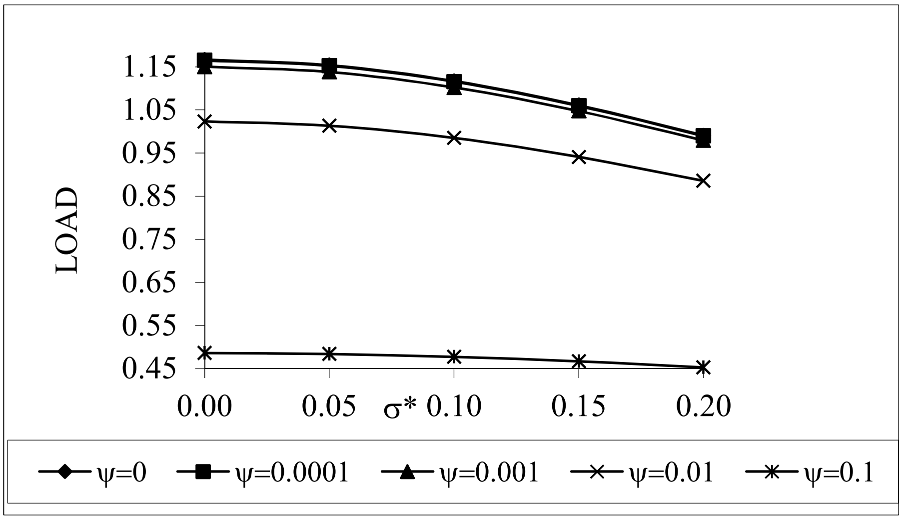

Figure: 8 Variation of load carrying capacity with respect to α^* and ε^*

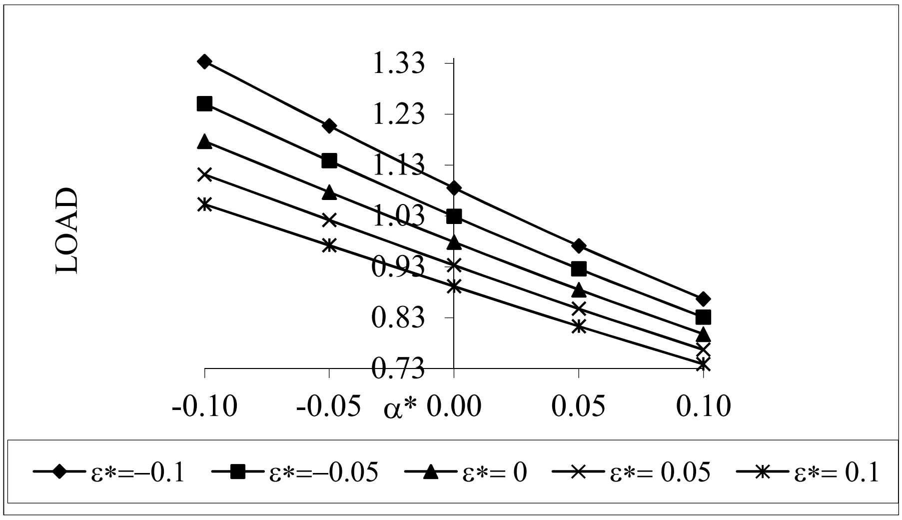

Figure: 9 Variation of load carrying capacity with respect to α^* and ψ

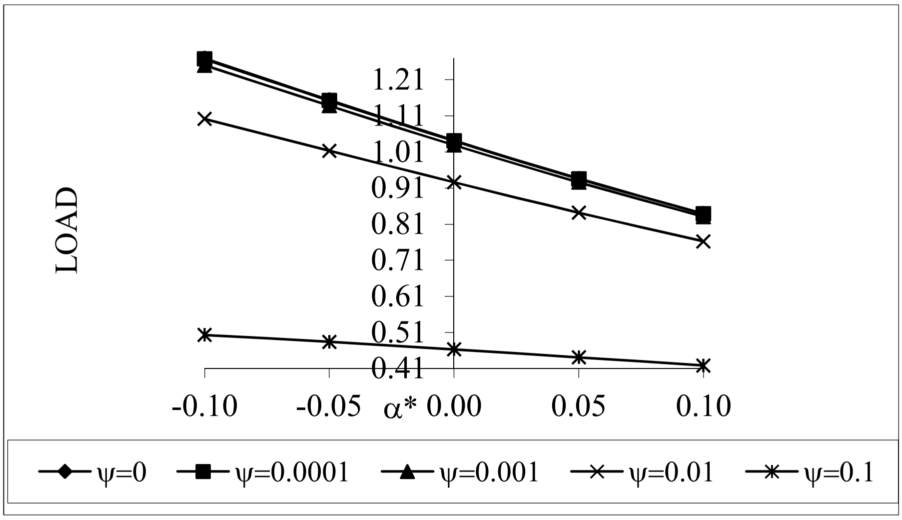

Figure: 10 Variation of load carrying capacity with respect to ε^* and ψ

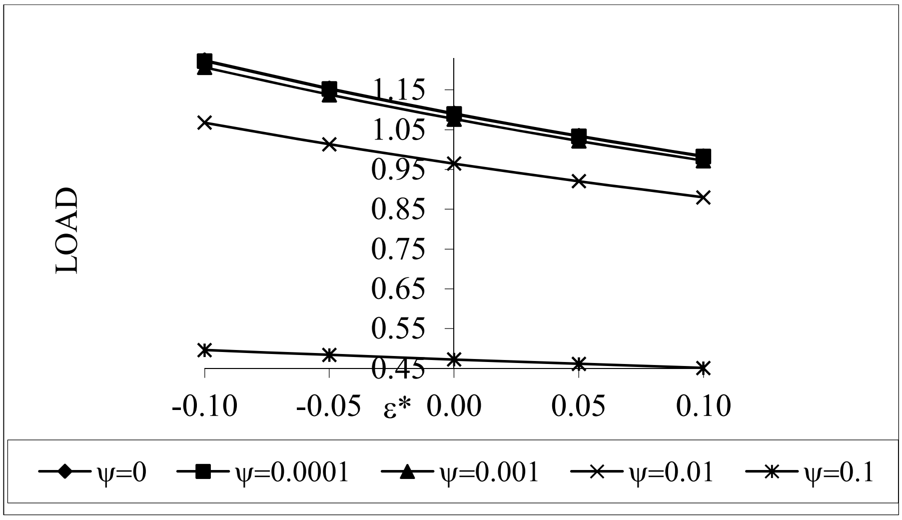

Figure: 11 Variation of load carrying capacity with respect to μ^* and σ^*

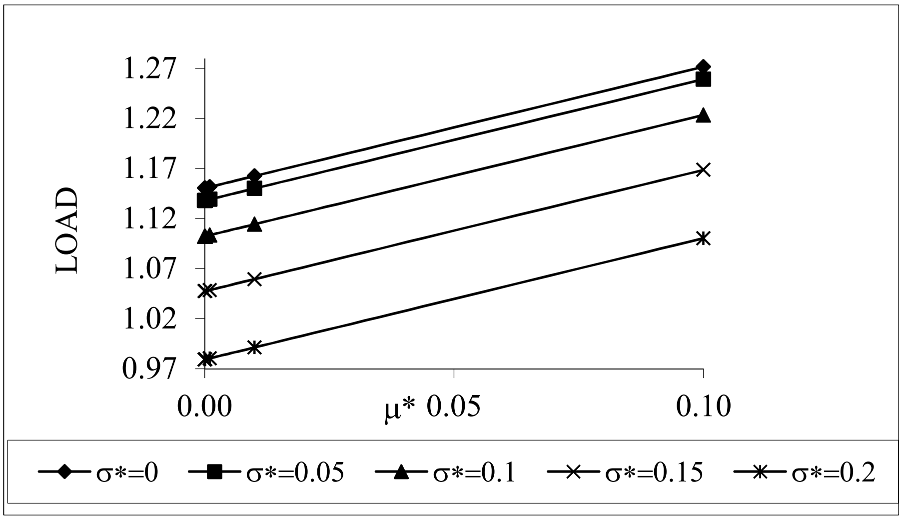

Figure: 12 Variation of load carrying capacity with respect to μ*and α^*

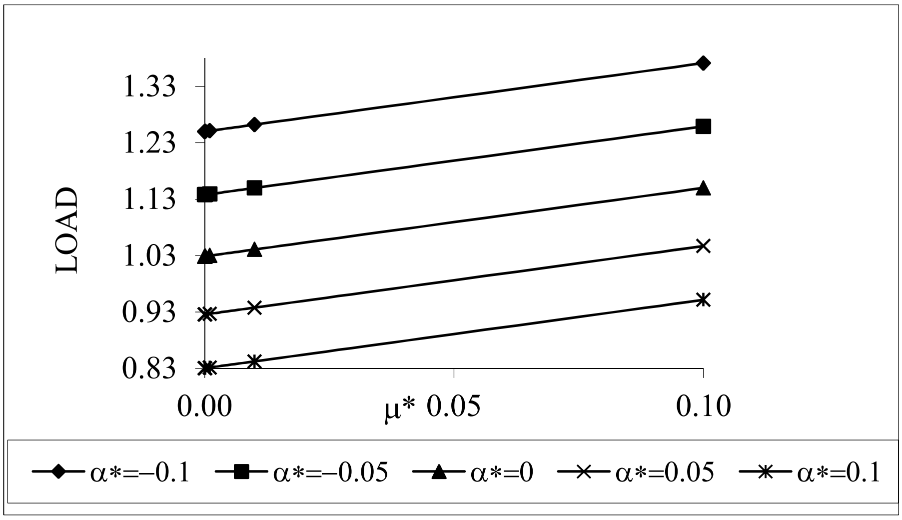

Figure: 13 Variation of load carrying capacity with respect to μ* and ε^*

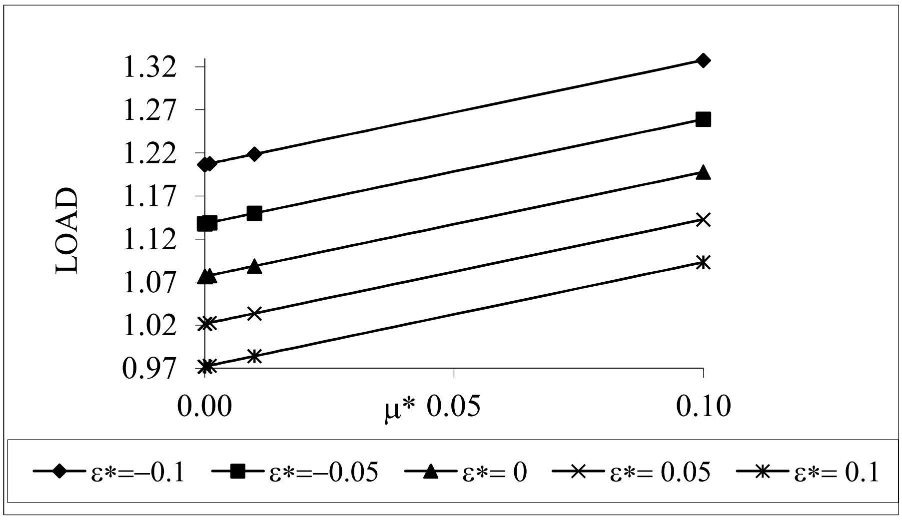

Figure: 14 Variation of load carrying capacity with respect to μ* and ψ